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Discussion on β Cephei and SPB stars

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Aerts: It makes me happy that we have the largest number of posters in this session. Wojtek gave a great range of topics for us to discuss, for instance the Be stars. I have also seen some evolution over the past 10 years, in the good interaction between observers and theorists on the subject which I think is very important. Is there anybody who would like to address a questions on these topics to the speakers or to the poster authors or to the audience?

Christensen-Dalsgaard [to Dziembowski]: What do you see in the foreseeable future as the prospect for a realistic and reliable and accurate, and maybe even physically correct, treatment of rapid rotation and pulsation?

Dziembowski: There are two approaches and they give different answers. There is the traditional approximation, and the expansion into the associated Legendre functions. Each of them has advantages. The traditional one is easier and this is why we are using it. I think that we need a numerical 2D models of linear adiabatic pulsations in rotating stars. Furthermore, our models ignore centrifugal distortion. One important consequence of including this effect of distortion is a nonuniform distribution of the temperature across the surface. The result is that you may have driving only in the equatorial regions which, in this case, will cause some modes to be preferred. This is important and I encourage young people to work on this problem.

Roxburgh: I should point out that at least to me, there was impressive progress on the modelling of adiabatic oscillations - so far only polytropes - by Daniel Reese, Francois Ligniéres and Michel Rieutord. What they show, essentially from full 3-D modelling of oscillations, is that the perturbation approximation breaks down at rotational velocities of the order of 50 km/s for models of the δ Scuti type. For very many stars we therefore need to go beyond linear calculations, and these authors' recipes can be extended to realistic models of stars.

Dziembowski: Fortunately, significant nonadiabatic effects arise only in the outer layers where the plane-parallel approximation applies. Therefore for determining the mode geometry the adiabatic treatment is likely sufficient.

Reed: Looking at multicolour observations, I'm curious to know how well the observations are constraining the modes and by how much they are matched by the models.

Aerts: The stars that have been modelled so-called successfully, are all slow rotators. The reason is that they are easier for the reasons just mentioned. Then we have a frequency spectrum that's not very dense for β Cephei stars (in contrast to the SPB stars, for instance). So in that sense we have very good matches with the frequency values, but we do have excitation problems as Wojtek clearly tried to explain. This is very important to be solved. I think that, for the moment, we have very good data on β Cephei pulsations, we know quite well how to model the slowly rotating ones, but we are missing frequency matches and this tells us about missing physics. We need more theoretical work on the mode selection mechanism. We do not understand how this works and it would be great to know if someone told us that.

Reed: How many of these stars have good mode identifications?

Aerts: Between two to five, but more is coming up. There are data sets where the identification is still ongoing, but in addition to the photometry we do need the spectroscopy.

Paparo: It happened that different data sets led to different mode identifications. Are these single data sets for all stars or are the observations repeated over several seasons? The problems usually come when there are more and more observations. For example, the δ Scuti star XX Pyxidis was regarded as simple and when more data became available it became more and more complicated. I expect this will be similar for your β Cephei and other B-type stars.

Christensen-Dalsgaard: It's wonderful that you got all the data that Andrzej talked about for β Cephei stars. But how are we going to address the issues of follow-up that will be required - and of course I am going to use this as an advertisement for the talk by Frank Grundahl tomorrow on the SONG network - to be able to analyse these stars in detail and see the problems with them?

Aerts: For the two to five stars where we have this information, we have very long-term monitoring. Our multisite campaigns lasted five to six months and we can add data from season to season. The data that Wojtek showed for ν Eri imply that we have stable modes. For 12 Lac, we see the same main six frequencies as were seen in 1978 and 1991. For B stars it's therefore much easier than for δ Scuti stars because the modes stay and that helps a lot.

Pigulski: What about Spica?

Aerts: This is a binary, it's an ellipsoidal variable, it's a high-degree pulsator and it's moderately rapidly rotating. So we have it all, as far as complications are concerned, and it's a magnificent laboratory. So I agree we should do it. We have very concrete plans already for this star with the MOST team.

Breger: I really love this discussion. Ten to fifteen years ago there was a lot of criticism when someone concentrated on one or two objects to really find out what is going on. And now you show that this is just the approach that allowed you to discover what is really happening in β Cephei stars. In some way this answers Margit's comment as well. She said that you need more than one data set to detect the complexity of real stars. There are two explanations for detected changes: first, the star has changed and second, you over-interpreted your first data set. Therefore, I would like to make a plea to those of you who referee papers to support the immense efforts that go into observing single objects.

Aerts: I would like to add to the remark made by Gerald this morning on the MOST photometry where lots of frequencies were claimed and perhaps that's a bit optimistic. I can tell you that I was guilty of that. It is true that only if you go back season to season to have trustworthy values to give to the theoreticians. So even with high-quality data from space we do need long-term monitoring.

Bedding: This also applies to solar-like stars. But I would like you to tell us about strange modes...

Dziembowski: This concept was introduced in the context of very nonadiabatic pulsation in luminous (high L/M ratio) stars. There are two different definitions of strange modes. First, I will tell you the one that I like and then I will tell you the one I don't like. The one I like is that if a mode does not have its adiabatic counterpart it is a strange mode. What is the adiabatic counterpart? You can scale down nonadiabatic effects, for instance by gradually increasing stellar mass. If you land on an adiabatic mode, in the sense that the difference between the adiabatic and the nonadiabatic mode frequency is small, then this is an ordinary pulsational mode for me. If you land on a thermal non-oscillatory mode, this is a strange mode. Some people, however, call a mode strange if it is trapped in a near-surface cavity around the hydrogen or helium ionization zones.

Bedding: As an observer, what should I observe to see a strange mode?

Dziembowski: There is no way of identifying modes by pure observational means.

Gough [to Bedding]: May I add to that? If you observe modes that have dynamical importance, and if we know what they are, theorists can use that to learn something about the structure of the star and its dynamics, and that's important. Whether or not some theorist classifies it as a strange mode is really not relevant. So it's not really an important question to you. What is important to you is that you measure modes that are dynamically interesting.

Aerts: There is a poster by Hideyuki Saio on a MOST data set on a supergiant SPB. That one is located between the Wolf-Rayet/LBV-type stars and the much easier β Cephei stars. There are lots of frequencies detected (never mind whether they are resolved or not, but they are there), and this star is just an extension of the SPB star instability strip to the upper part of the HR diagram. These are not strange modes to me, but maybe by someone else they would be termed like that. I find that extremely interesting because it will allow us to calculate the upper part of the HR diagram. This is a little related to your question because it's related to nonradial oscillation modes in supergiant stars.

Dupret: I agree that much work has to be done to study the interaction between rotation and oscillations in rapid rotating stars. However I stress that many β Cep stars are slow or moderate rotators. For some of them observed in multi-site campaigns (e.g. HD 129929, θ Oph, ν Eri) rotational splitting is clearly seen. Their study allows to probe internal rotation, without the theoretical difficulties and uncertainties associated with fast rotation. This is very interesting as it allows to test theories of angular momentum transport. So it is time to include these transport mechanisms in our stellar evolution codes, we can constrain them now!

Kepler: I would like to point out the difference between frequencies and modes. Sometimes, especially in white dwarfs, you have hundreds of combination frequencies which are not modes. You may want to make a clear distinction between frequencies and modes to avoid an over-interpretation of data.

Matthews: I agree. We constantly look at and identify combination frequencies. We certainly recognize that distinction and when we make an identification we don't use the term "modes" unless there is some theoretical match.

Kepler: Sometimes combination frequencies do excite real modes, by resonance. We must also be very careful not to throw away all combination frequencies because sometimes they are real modes. I'm just saying we must be very careful in separating modes and frequencies.

Breger: This is an important problem. I would like to advertise a new paper by Katrien Kolenberg and myself which shows that there actually exists a case where a combination frequency excites a mode separated by a minuscule amount of 0.7 nHz. We had to combine photometry covering several decades to obtain the required frequency resolution. This shows that combination frequencies are extremely important. We also find that positive combinations (sum of frequencies) usually have higher amplitude than their negative counterparts.

Gough [to Kepler]: I would like to add to your comment. The existence of harmonics and combination frequencies are indications of the existence of nonlinearity, which is extremely interesting. For the analysis, we not only need to know the amplitudes of the combination frequencies, but also their relative phases. May I make a plea to observers to publish relative phases in addition to the amplitudes?

Dziembowski: There is no easy way to make a distinction between the cases of resonant mode excitation and a simple harmonic light curve distortion. The reason is that there is a phase-lock induced by nonlinear mode coupling, which cancels the departure from the exact resonance (frequency mismatch). As a result, in the frequency domain we see a simple harmonic. The only way to say there is a resonance is an abnormal enhancement of amplitude at the harmonic frequency. This is what we see in the case of Bump Cepheids, where the second overtone has frequency close (but not equal) to twice that of the fundamental mode.

Bourge: To drive all the modes observed in β Cephei stars, one must increase the iron abundance in the driving zone. But one doesn't see the abundance patterns expected on the surface, as Wojtek Dziembowski said in his talk. We spoke about mixing, but this is not the only process modifying the chemical abundances. In my models, when I include mass loss, I find this has a big influence on the chemical composition even in the driving region. But we do not include that in the current "standard" models.

Aerts: Then I have one final comment to make. Can anyone tell us how one can discriminate between convection and rotational mixing? With that I would like to thank you very much for this discussion.

Pulsating white dwarf and sdB stars